Renewable and Sustainable Energy Reviews 35 (2014) 258–264

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Evaluating energy benefit of *Pistacia chinensis* based biodiesel in China

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ARTICLE INFO

Article history:
Received 10 July 2013
Received in revised form
14 March 2014
Accepted 7 April 2014
Available online 25 April 2014

Keywords:
Pistacia chinensis
Biodiesel
Energy efficiency
Potential productivity

ABSTRACT

To be an alternative to fossil fuel, biodiesel should provide a positive energy benefit and a sustainable energy income. Based on the principles of Life Cycle Analysis and using the energy benefits of exploiting *Pistacia chinensis* in China as a case study, this paper presents a quantitative evaluation of the energy consumed throughout the six-phase life cycle process, which includes planting, fruit transport, oil production, biodiesel production, biodiesel transport and biodiesel combustion. The results show that during the life cycle process, the total energy consumption of the biodiesel production and transformation phase is the greatest and that energy consumption during the plantation phase second greatest. The results indicated that the potential maximum gross annual production is approximately 162.19 billion MJ per year for suitable land and 117.20 billion MJ per year for lands classified as fairly suitable, which could produce 6.35 million t of biodiesel. Considering the net energy production and output potential for *P. chinensis* based biodiesel at the provincial level, Yunnan Province has the most amount of production potential, while Beijing City has the least amount of production potential. The annual output value created by *P. chinensis* based bio-fuel is 3007.83 million Yuan in China.

Contents

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http://dx.doi.org/10.1016/j.rser.2014.04.019
1364-0321/

1. Introduction

Fossil fuel shortages and environmental pollution problems are worsening, while globally, countries are actively seeking alternative energy sources. Over the past few decades, to guarantee energy security and protecting ecological environment, China has promoted development of bio-liquid fuel such as bio-ethanol and biodiesel. Biodiesel, which has good combustion performance, is environmentally friendly and has an ability to regenerate, has become a viable renewable energy [1]. The Chinese government is developing bio-liquid as one of its transportation fuels for energy security and environmental improvement purposes [2]. The proportion of renewable energy in the total energy is 8% and the percentage of alternative fuel for vehicle will be up to 20% as planned in 2020. The production of biodiesel should be up to 2 million tons in 2020 according to the plan of National Development and Reform Commission (NDRC).

As feedstock for biodiesel, *Pistacia chinensis* is one of the notable plants for renewable energy in China. It is resistant to drought and salinity and can grow in various types of soil where other crops, such as soybean, flax, *Jatropha curcas. L* and *Ricinus communis* cannot grow well. *P. chinensis* fruit oil content ranges from 35% to 42.46%, and oil extraction rate is 22–30% [3]. The carbon chain length of *P. chinensis* biodiesel is very close to that of the ordinary diesel, thus its oil is very suitable for biodiesel production. An accurate assessment of its resource potential, however, is necessary to develop *P. chinensis* in China. To be a suitable substitute for fossil fuels, bio-liquid fuel should be able to provide a net energy income, positive energy income and economic benefits, and not reduce the food supply and increase greenhouse gas (GHG) emission during mass production [4,5]. Life Cycle Analysis (LCA) is a method used to evaluate the energy consumption of a product or system throughout its lifespan, that is, from raw material acquisition, production, and product use through to post-processing [6]. In recent years, LCA has been widely used in domestic and international bio-energy assessment studies [7,8]. Relevant research has been calculated and evaluated on the land use, water and energy consumption of three feedstock, namely, rapeseed oil, *J. curcas L.* oil and waste oil using LCA, including planting, harvesting and transportation, pretreatment, biodiesel production, distribution and consumption [1,9]. The costs, energy consumption and environmental impacts of the bio-ethanol life cycle, which used wheat, corn and sweet potato as raw materials, have been analyzed [10,11]. Other researchers [12–14] compared the life cycle and energy consumption of bio-liquid fuel with fossil fuels and found that bio-fuel consumed less primary energy and reduced CO_2 emissions when taking into account that the bio-liquid fuel replaced some fossil fuels. Literatures on *P. chinensis* are relatively less than those of above mentioned energy plants and usually focused on certain phase of the *P. chinensis* based bio-fuel production. Yu et al. investigated the use of CaO–CeO_2 mixed oxides as solid base catalysts for the transesterification of *P. chinensis* oil with methanol to produce biodiesel [15]; Qin et al. compared three extraction methods to obtain seed oil of *P. chinensis*, and suggested that the Soxhlet extraction was the most effective method [16]. Luo et al. tested the effect of injection timing on combustion characteristics of a direct engine fueled with different *P. chinensis* seed biodiesel [17]. Ma et al. analyzed the emissions of a diesel engine fueled with *P. chinensis* seed biodiesel–diesel blends, and found that CO, HC and exhaust smoke emissions decrease with the increase of the proportions of biodiesel in the blends [18]. However, there are no similar reports regarding the life cycle energy consumption and environmental emissions for *P. chinensis* at present.

Based on the results of previous studies, the main objective of this paper is to (1) estimate the net energy production potential of *P. chinensis* biodiesel in China, (2) present a nationwide quantitative evaluation of its energy efficiency as a source of biomass energy and (3) calculate available direct economic benefits.

2. Methodology

2.1. Sources of research data

In this study, the data sources include the life cycle stages and land resources that are suitable for planting *P. chinensis*. Currently, there are no production plants producing biodiesel from *P. chinensis*. Pilot studies on producing biodiesel with *P. chinensis* have been performed by [19,20]. In this paper, biodiesel production technology and biodiesel conversion process data referred to *J. curcas L.* production data and the pilot study data on *P. chinensis*.

In our previous studies, we established a comprehensive evaluation model for identifying land suitability for *P. chinensis* in China [21]. The model is based on space-gridded data and evaluates the potential for large-scale planting on marginal land through a spatial distribution analysis using a combination of a multi-parameter assessment method and limited policy factors. Previous studies classified marginal land into three categories: suitable for growing, fairly suitable for growing and unsuitable for growing *P. chinensis* [21,22]. The area classified as suitable for growing *P. chinensis* is approximately 7.10 million ha, and the suitable land area totals 12.79 million ha [21].

2.2. Energy analysis of Pistacia chinensis biodiesel life cycle processes

LCA for *P. chinensis* based biodiesel consists of six phases: *P. chinensis* planting and treatment, transporting harvested fruit, oil production, biodiesel conversion, biodiesel transport and distribution; biodiesel combustion. In each phase, the raw material and energy consumed will be calculated based on the energy conservation principle and the law of material invariance [9,13]. The life cycle energy flow of *P. chinensis* biodiesel was shown in Fig. 1.

(1) *P. chinensis* planting and treatment
As shown in Fig. 1, *E*1 represents the energy consumed during the feedstock's growth, including soil preparation, cultivation, fertilizer applications, pesticide spraying, fruit harvesting and drying, husk removal and so forth, which primarily consists of inputs including land, labor, seedlings, fertilizers, machines and energy.

(2) Transport of harvested fruit
E2 represents the energy consumed during the fruit transportation stage. We assumed that fossil energy was consumed during the transportation stage and only diesel vehicles were used.

(3) Oil production and biodiesel conversion
Raw oil production consists of extracting oil from *P. chinensis* fruits through leaching. E3 represents the energy consumed through the use of material inputs, electricity and water. E4 represents the energy used during the bio-liquid fuel production process, which involves producing a synthetic *P. chinensis* biodiesel blend from the transesterification of oil with methanol.

(4) Biodiesel transportation and distribution
E5 represents the energy consumed during the biodiesel transportation and distribution process, which means transport from plant to gas station. It mainly consumes diesel and electricity.

(5) Biodiesel combustion
Biodiesel combustion means the life cycles for biodiesel fuel at the end-use stage in a truck, bus, and car, etc. In this study, the

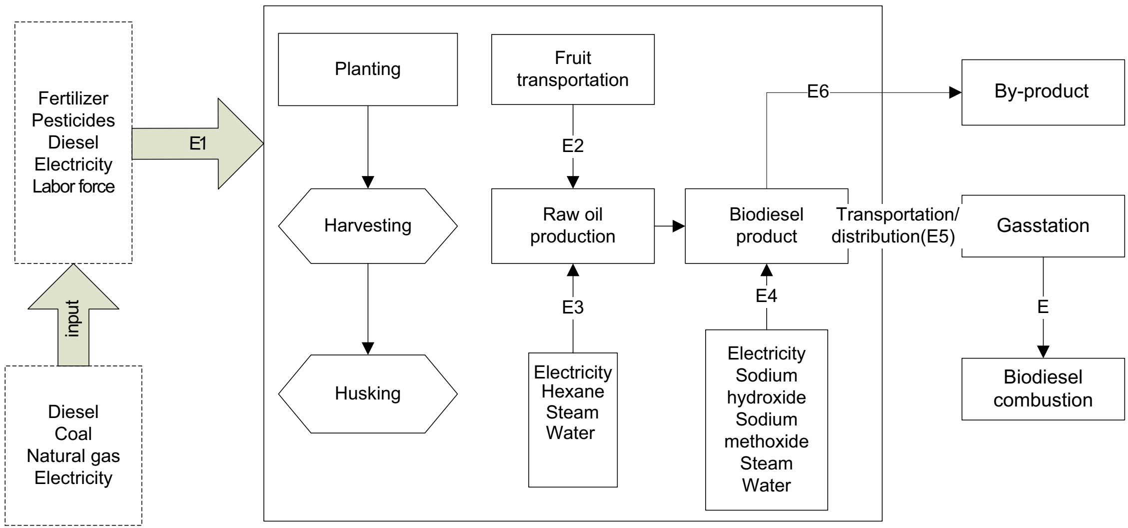


Fig. 1. Life cycle energy flow of *Pistacia chinensis* biodiesel.

Lower Heating Value (LHV) represents the energy provided by biodiesel through final combustion, or E.

To consider the share of by-products in *E*4, energy substitution was used, that is, the energy output from by-products was *E*6, as shown in Fig. 1.

2.3. Life Cycle Analysis of net energy model

The relationship between the life cycle of *P. chinensis* biodiesel, fossil energy inputs and bio-energy output is based on the first law of thermodynamics. The energy balance can be quantified by comparing the energy inputs required in each life cycle assessment stage and then comparing the total required energy inputs with the embodied energy of the biodiesel product. In this analysis, net energy is used to calculate energy efficiency because it is the net energy (NE) yield that measures the true value of an energy resource to society. The net energy available from a fuel is equal to:

$$\mathrm{NE} = E-(E1+E2+E3+E4+E5-E6) \qquad (1)$$

where E is the total energy income during its life cycle production, as illustrated in Fig. 1 in this case, and *E*1, *E*2, *E*3, *E*4, *E*5 and *E*6 represent the energy consumed during each stage described in Section 2.2 and are calculated by the formulas shown as (2)–(8). These formulas are based on the first law of thermodynamics; the energy flow analysis throughout the whole process quantitatively evaluates the energy sustainability in different production conditions (*P. chinensis* production, diesel production technology and energy utilization, etc.):

Energy income:

$$E = LHV \qquad (2)$$

planting:

$$E1 = \sum_{i=1}^{n} E_h X_i \qquad (3)$$

fruit transport:

$$E2 = d_1 E_h x_j \qquad (4)$$

raw oil production:

$$E4 = \sum_{i=1}^{n} E_h X_i x_j \alpha \qquad (5)$$

Table 1
Data sources of *Pistacia chinensis* biodiesel production.

Life cycle stage	Items	Sources
Planting	Fertilizer	Refs. [19–21], yearbook, GREET
	Pesticides	Refs. [19–21]
	Electricity and fuel consumption	Refs. [19–21], GREET, 〈GB/T 2589-2008〉
	Yield	Refs. [21], yearbook
	Not take into account factors: Irrigation water, labor force	
Transport	Fuel consumption	Refs. [19,20], China Traffic Yearbook, GREET
	Transport distance	China Logistic Yearbook, Ref. [21]
	Not take into account factors: Vehicle loss, labor force	
Production conversion	Coal, steam, electricity	Refs. [19,20], investigation, 〈GB/T 2589-2008〉
	Chemical reagents	Refs. [19,20], yearbook
	By-product output	Refs. [19,20], investigation
	Not take into account factors: Plant, water, labor force	
Distribution	Electricity	〈GB/T 2589-2008〉

biodiesel production:

$$E4 = \sum_{i=1}^{n} E_h X_i x_j \gamma \alpha \qquad (6)$$

biodiesel transport:

$$E5 = d_1 E_h x_j \gamma \alpha \qquad (7)$$

byproduct production:

$$E6 = \sum_i (EW_i M_i) \qquad (8)$$

In the above formulas [9,13], LHV is the Lower Heating Value of biodiesel combustion; that is, reaction heat is released by biodiesel with complete combustion and steam from the combustion product condensing into gaseous water. Accordingly, the major energy consumption parameters and numbers of *P. chinensis* were listed in Table 2.

In the planting phase, the energy (*E*1) could be calculated using formula (3). Where X_i stands for the amount of energy consumption during the plantation process, E_h is the energy intensity, that is, the energy consumption (such as fuel and power) of a unit of product, including fertilizer, pesticides, electricity and fuel

consumption. The indirect energy or material consumptions during the entire life cycle were also added. The main parameters were described and listed in Tables 1 and 2. X_j is unit yield of *P. chinensis* fruits in the *j* type of land, α is the oil extraction rate of *P. chinensis* fruits and γ is the conversion rate of *P. Chinensis* biodiesel. EW_i represents the energy substitute coefficient of the byproduct at the biodiesel production stage, and M_i represents byproduct yield.

The energy ratio (ER) can be used to measure energy efficiency as well. The net energy available from a fuel can be calculated as formula (9) [23,24]:

$$ER = \frac{E}{E1 + E2 + E3 + E4 + E5 - E6} \tag{9}$$

Formulas of the direct economic benefits of biodiesel as follows:

$$V_{biodiesel} = P_{diesel} \times v_{biodiesel} \times C_{water} \tag{10}$$

where, $V_{biodiesel}$ is the direct economic benefits of biodiesel, Yuan; P_{diesel} is the market price of diesel, Yuan; $v_{biodiesel}$ is the volume of gained alternative biodiesel, ton; C_{water} is the moisture content of biodiesel, %.

Table 2
Major energy consumption parameters and values of *Pistacia chinensis*.

Input material	Value (kg/ha)	Energy consumption parameters (MJ/t)
Nitrogenous fertilizer (ammonium bicarbonate)	75	18,763.63
Phosphate fertilizer	150	10,793
Potassium fertilizer	30	5000
Urea	7.5	47,048.23
Pesticide	75	259,780
Electric	11 (kwh/ha)	11.846
Diesel	18 (L/ha)	42,652
Sodium hydroxide	12	1.559
Sodium methylate	24.06	32.159
Methyl alcohol	100	32.426
Steam	660	3763
Water	165	0.705

Table 3
Energy consumption for *Pistacia chinensis* biodiesel system in the whole life cycle.

Life cycle processes	Suitable		Fairly suitable	
	Energy consumption (MJ)	MJ/L	**Energy consumption** (MJ)	MJ/L
Planting	9337.69	6.16	9337.69	10.71
Fruit transport	1119	0.74	643.43	0.74
Oil production	5041.19	3.32	2898.69	3.32
Biodiesel production	12,197.53	8.04	7013.59	8.04
Biodiesel transport	427.68	0.28	245.92	0.28
Distribution	3.82	0.003	2.20	0.003
Total	28,126.91	18.54	20,141.52	23.09

3. Results and analysis

3.1. Net energy analysis of Pistacia chinensis biodiesel life cycle assessment

This research found that the high and low yields of *P. chinensis* fruits were 4 t per ha and 2.3 t per ha, respectively, after investigating existing references. According to the current biodiesel production situation in China, *P. chinensis* fruits and biodiesel are transported by diesel trucks, with average transport distances of 250 km and 300 km, respectively. The consumption efficiency of a diesel lorry is 0.063 $L \cdot (t\,km)^{-1}$. Using the above formula and parameters, the results for the total energy consumption per unit area of *P. chinensis* biodiesel life cycle are shown in Table 3 and Fig. 2.

The MJ/L means that produces 1 L biodiesel the total energy consumed in each unit process. The biodiesel production and transformation phase used the greatest amount of the total energy consumed. This amount accounted for 61.29% of the total energy for lands classified as suitable with raw oil production totaled 17.92% and biodiesel transformation totaled 43.37%, and 49.21% of the total energy for lands classified as fairly suitable, with raw oil production comprising14.39% and biodiesel transformation comprising 34.82%. The high energy consumption and large number of input chemicals and materials may account for the highest energy consumption at this stage. The *P. chinensis* planting phase accounted for the second highest amount of energy consumed, comprising 33.20% of the total energy on suitable lands and 46.36% on fairly suitable lands because more fertilizers and pesticides are necessary. The harvested fruits and biodiesel transport phase represented energy consumption percentages of 3.98% and 1.52%

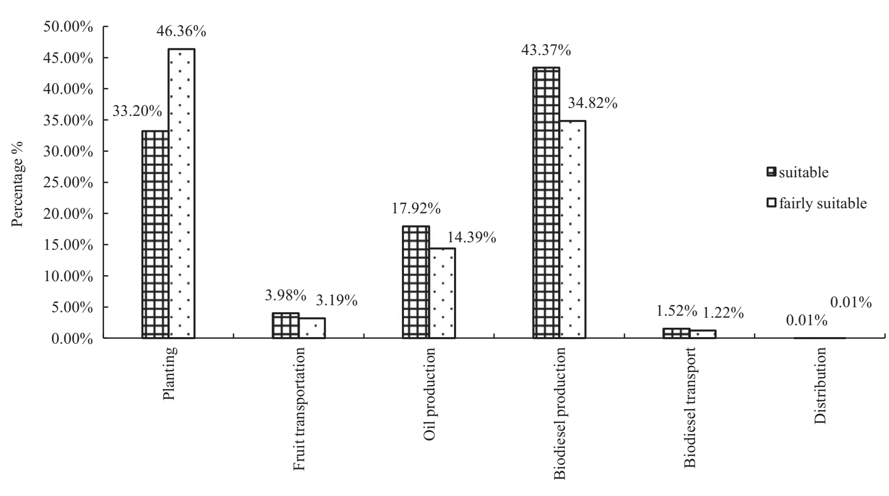


Fig. 2. Total energy consumption of *Pistacia chinensis* LCA.

for suitable lands and 3.19% and 1.22% for fairly suitable lands, respectively. As shown in Fig. 2, the distribution process consumes the least amount of energy.

Energy consumption during the biodiesel production stage is 8.04 MJ/L, which requires the most amount of energy during the entire life cycle. During the planting stage, energy consumption is 6.16 MJ/L for suitable land and 10.71 MJ/L for land classified as fairly suitable. For the fruit transport and biodiesel transport stage, the consumed energy is 1.02 MJ/L.

In the long term, more productive *P. chinensis* varieties and more energy-efficient conversion technologies need to be developed to increase the returns from land and reduce the overall energy consumption during the fuel conversion process. Based on the above results, the life cycle energy consumption of biodiesel on the two suitability categories of land were 18.54 MJ/L and 23.09 MJ/L, respectively.

3.1.1. *Pistacia chinensis planting and treatment*

Energy consumption during this process includes energy for the production and transportation of fertilizers, pesticides and so on, energy consumption for planting of *P. chinensis* with mechanical tool using electricity. The value of energy consumption in this process is shown in Table 4.

As shown in Table 4, fertilizer inputs, including nitrogen, phosphate, potassium and urea, comprise 71.81% of the total energy consumption in the planting stage. Urea consumed considerably more energy, mainly due to high energy needs during urea production processes. Second, the energy consumption of pesticides accounts for 20.87% of the total energy consumption. Diesel consumption is mainly used for cultivation, short-distance transport from the land to the farmers' homes and agricultural machinery consumption during post-processing; power consumption is relatively small, primarily consisting of fruit harvesting, drying, husking and packaging. Although increasing investments of fertilizers and pesticides can improve *P. chinensis* fruits yield, they did not exhibit a simple linear relationship because increasing fertilizers and pesticides inputs may also result in higher fossil energy consumption. Consequently, it is recommended that famers instead improve ecosystem management, use green manure and increase production to reduce plantation energy consumption. Due to high energy usage and considerable inputs of materials, it is necessary to optimize oil extraction and production processes to improve yield and conversion rates, thereby reducing energy consumption. Diesel consumption during the transport process and power consumption during the distribution process consumed comparatively less energy.

3.1.2. *Oil production and biodiesel conversion*

The type of energy consumption during oil production and biodiesel conversion stages includes electricity, steam and some chemical materials. Energy consumption for each process step is shown in Table 5.

Table 4
Energy consumption for *Pistacia chinensis* planting.

Item	Energy consumption (MJ)	Proportion (%)
Nitrogenous fertilizer (ammonium bicarbonate)	1407.27	15.07
Phosphate fertilizer	1618.95	17.34
Potassium fertilizer	150.00	1.61
Urea	3528.62	37.79
Pesticide	1948.35	20.87
Electricity	39.60	0.42
Diesel	644.90	6.91
Total	9337.69	100.00

Table 5
Energy consumption for oil production and biodiesel conversion.

Stage	Item	Suitable land (MJ)	Fairly suitable land (MJ)
Oil production	Electricity (KWh)	792	455.4
	Hexane (kg)	0.78	0.45
	Steam (kg)	4214.56	2423.37
	Water (t)	33.85	19.47
	Total	5041.19	2898.69
Biodiesel conversion	Electricity (kW h)	165.11	94.94
	Sodium hydroxide(kg)	22.67	13.04
	Sodium methoxide(kg)	937.87	539.28
	Methanol (kg)	7860.78	4519.95
	Steam (kg)	3164.08	1819.35
	Water (t)	47.02	27.03
	Total	12,197.53	7013.59

Table 6
Energy consumption for fruit transport and biodiesel transport.

Stage	Distance (km)	Suitable land (MJ)	Fairly suitable land (MJ)
Fruit transport	250	1119	643.43
Biodiesel transport	300	427.68	245.92

3.1.3. *Fruit transport and biodiesel transport*

The fruit of *P. chinensis*, which are treated by farmer, are distributed to biodiesel plant by truck. Converted *P. chinensis* biodiesel is distributed to gas station by trucks. Energy consumption for each step is shown in Table 6.

The energy consumption of suitable land is higher than the energy consumption of fairly suitable land because the higher yield in suitable land. Energy consumption for biodiesel transport stage is lower than fruit transport stage caused by the conversion rate of *P. chinensis* biodiesel and the oil extraction rate of *P. chinensis* fruits.

3.1.4. *Allocation of byproducts*

Producing *P. chinensis* biodiesel results in a number of byproducts including oil residue, methane, glycerol and biomass waste. There are few references on the comprehensive utilization of *P. chinensis* biodiesel byproducts; this investigation selected a substitute coefficient of 0.24 for *P. chinensis* byproducts by referencing data for *J. curcas L.* After calculating an allocation for byproducts, the net energy results for *P. chinensis* biodiesel are shown in Table 7.

When the energy requirements of byproducts are not considered, the net energy of *P. chinensis* biodiesel on suitable land and fairly suitable land is 15.06 MJ/L and 10.50 MJ/L, respectively, with an ER of 1.81 and 1.46, respectively. In contrast, when the energy requirements of byproducts are considered, both net energy and ER increase substantially (Table 7). Net energy requirements rise to 19.51 MJ/L and 16.05 MJ/L on suitable land and fairly suitable land, respectively, with an ER of 2.38 and 1.91, respectively. Consequently, the full use of byproducts is an important consideration in improving energy efficiency.

Table 7
Allocation results of energy consumption for *Pistacia chinensis* biodiesel.

Energy substitution	Byproduct energy	Before the energy allocation		After the energy allocation	
	(MJ/L)	Net energy (MJ/L)	Energy ratio	Net energy (MJ/L)	Energy ratio
Subtable	4.45	15.06	1.81	19.51	2.38
Fairly suitable	5.54	10.50	1.46	16.05	1.91

3.2. *Evaluating the marginal land resources suitable for developing Pistacia chinensis biodiesel in China*

In order to estimate the potential of alternative biodiesel from *Pistacia chinensis*, firstly, we calculate the numbers of lands suiting for planning *P. chinensis* use the land mode, and then, we calculate the energy consumption in each stage depending on the numbers of each type of land according the formula. According to previous studies [22], China has 19.90 million ha marginal land suitable for growing *P. chinensis*, 7.10 million ha of which is suitable land and the remaining 12.79 million ha is fairly suitable land. The net energy yield of suitable land is approximately 162.19 billion MJ per year, much more than that of fairly suitable land (117.20 billion MJ per year). If all of the net energy could be utilized, it would amount to approximately 6.35 million t of substitute biodiesel. Following [25] three development scheme for producing biodiesel, the net energy of China's annual production of bio-liquid fuel would be equivalent to 6.35 million t, 4.45 million t and 1.90 million t of diesel through the use of 100%, 70% and 30% of the marginal land resources. Currently, the energy consumption structure in China is dominated by coal, while oil consumption comprises approximately 20% of the structure. According to static medium-long term plan (through the year 2020), there is annual output of 12 million tons of bio-liquid fuel. Assuming that 30% of the marginal land area can be used and is only planted with *P. chinensis* as source of biomass energy, it could potentially provide 15.8% of the biodiesel (Table 8).

Table 8
Total net energy potential for *Pistacia chinensis* biodiesel production in China.

	The area of exploited land (Million ha)	**Unit energy** (MJ/L)	**Net energy** (Billion MJ)	**Substitute diesel** (Million t)
Suitable	7.10	15.06	162.190	3.69
Fairly suitable	12.79	10.50	117.201	2.66
Total			279.392	6.35

Yunnan has the largest net energy and biodiesel annual output, accounting for 16.53% of the total production. The Shaanxi and Guizhou Province rank second, with a proportion of 15.60% and 10.59%, respectively. The net energy production potential in each province is determined by the area of marginal land classified as suitable and fairly suitable for planting *P. chinensis*. Yunnan and Guizhou Province, located in southwest China, with good moisture, temperature, sunshine, and a relatively high concentration of available marginal land resources, are suitable for developing the large-scale cultivation of *P. chinensis*. The provinces or municipalities with the least amount of production potential are Beijing, Jiangsu and the Tibet Autonomous Region, with suitable land totaling only 0.39%, 0.41% and 0.75%, respectively. Both Beijing and Jiangsu Province, which have a developed economy and high land use intensity, are dominated by lands for agricultural and construction purposes, have less land for growing *P. chinensis*. The Tibet Autonomous Region has ample sunshine but low precipitation and barren soils. Only a small area suitable for growing *P. chinensis* is found in southern Tibet (Fig. 3).

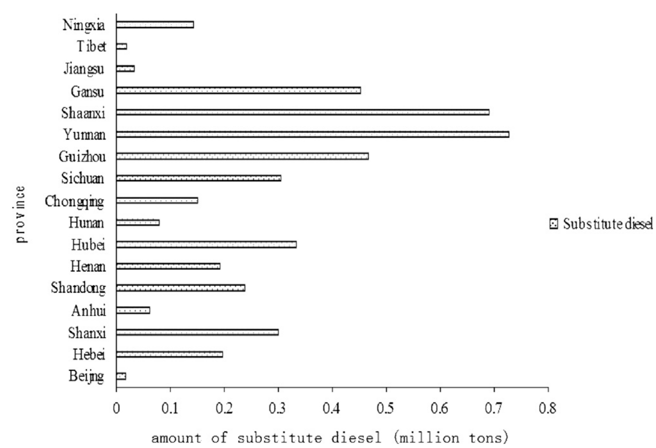


Fig. 3. Net energy potential for *Pistacia chinensis* biodiesel production in each province.

3.3. *Direct economic benefits of Pistacia chinensis biodiesel*

Energy shortage and structural contradictions have become increasingly prominent in china. It is the urgent need that to continue to promote the development and utilization of new alternative energy from the energy security strategy and implement quality energy-based energy development strategy. Biodiesel as an important complement to the diesel, its development and utilization can effective relieve the increasingly tense situation in the energy supply and demand, and promote the optimization of energy structure in order to achieve the sustainable development of energy, economic, environmental (Table 9).

Table 9
Output value of alternative biodiesel from *Pistacia chinensis*.

	Diesel price (Yuan/L)	Alternative diesel (Million t)	Annual output value (Million Yuan)
Suitable	0.46	3.69	1747.92
Fairly suitable	0.46	2.66	1259.91
Total		6.35	3007.83

The results calculated according to formulas (3) indicated that the annual output value created by alternative diesel is 3007.83 million Yuan, in which output values from suitable land and fairly suitable land are 1747.92 million Yuan and 1259.91 million Yuan, respectively.

4. Discussion

Based on Life Cycle Analysis theory, this article established a method for analyzing *P. chinensis'* net energy and conducted a

quantitative evaluation of the energy consumption during the six phases, which included planting, transporting harvested fruits, oil production, biodiesel production, transporting biodiesel fuel and biodiesel combustion. The total energy consumption during biodiesel production and transformation phase was the highest, and the cultivation phase ranked second. There was less consumption during the transportation and distribution stage. To prevent the application rate of fertilizers and pesticides becoming too high to cause much more energy consumption, it is recommended that famers strengthen their ecosystem management, use green manure and increase production to reduce plantation energy consumption. Due to high energy consumption and significant material inputs, it is necessary to optimize the oil extraction and production process to improve oil yield and conversion rates, thereby reducing energy consumption.

The results indicated that when the energy requirements of byproducts were considered, ER *P. chinensis* based bio-fuel on suitable land and fairly suitable land were 2.38 and 1.91, respectively, which were less than *J. curcas L.* based bio-fuel, but larger than *Cassava* based fuel ethanol: according to previous literatures, the ER for *J. curcas L.* based bio-fuel on the suitable and fairly suitable land in China are 3.762 and 3.079, respectively [26]; For *Cassava* fuel ethanol, the net energy are 8.857 MJ/L and 7.546 MJ/L on the suitable land and moderate suitable land, with the ER of 1.719 and 1.553, respectively [27].

5. Conclusions

According to the results from LCA based approach, reclaiming marginal land for the development of *P. chinensis* biodiesel will contribute to ease the energy crisis in China: the net annual energy yield of *P. chinensis* on suitable land and fairly suitable land are approximately 162.19 billion MJ per year and 117.20 billion MJ per year, respectively. It totals 6.35 million t of biodiesel in China. At the provincial level, Yunnan Province has the largest potential for net energy and *P. chinensis* biodiesel production, followed by Shaanxi and Guizhou Province, accounting for 16.53%, 15.60% and 10.59% of the total production potential, respectively. The annual output value created by alternative diesel is 3007.83 million Yuan; 1747.92 million Yuan is created by suitable land and the remaining 1259.91 million Yuan is created by fairly suitable land.

It is an effective way to cope with the depletion of fossil energy and develop a viable substitute energy source. But we also should be aware of the tremendous impact on biodiversity and ecology in general if such a large surface would be converted to a monoculture, which is another research field later.

Acknowledgments

This research was supported and funded by the Chinese Academy of Sciences (Grant no. KZZD-EW-08) and the High Resolution Earth Observation Systems of National Science and Technology Major (Grant no. 05-Y30B02-9001-13/15) Projects.

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